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Photovoltaic System Operation Status and MPPT Simulation Analysis Under Partial Shadow

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Abstract

As new energy technologies such as photovoltaic power generation have received more and more attention from the society, the maximum power point tracking technology (MPPT) of photovoltaic (PV) power generation has become a hot research object in recent years. The traditional MPPT technology has matured, but if the photovoltaic system works in partial shadows, the operating conditions of the system will become complicated. In this case, the traditional MPPT control technology can't correctly find the maximum power point. Therefore, in the case of partial shadows, this paper divides the photovoltaic system into "sub-columns" and "sub-strings" for analysis, and proposes an improved control method based on the perturbation and observation (P&O) method. Matlab/Simulink simulation model was established. The experimental results show that the proposed control method can enable the photovoltaic system to accurately track the maximum power point in the case of partial shadows.

Keywords

Maximum Power Point Tracking Technology (MPPT); P&O Method; Partial Shadows.

1. Introduction

Due to the increased environmental pollution caused by the burning of fossil fuels, it has become an obstacle to the sustainable development of today's society, making the development and utilization of renewable clean energy particularly important. Renewable energy represented by wind energy and solar energy is widely distributed in nature, and the environmental pollution caused by the development and utilization process is small. In recent years, more and more countries and regions have paid attention. Among them, photovoltaic power generation has received extensive attention due to its rich resources and environmental friendliness. However, photovoltaic cells are non-linear devices, and their output power changes all the time due to the influence of the external environment such as light intensity and temperature. In order to improve the conversion efficiency of photovoltaic cells to energy under certain conditions, and maximize the output of photovoltaic arrays, some algorithms need to be used to track the maximum power point(MPP)[1].

At present, the research on MPPT technology of simple photovoltaic systems has been relatively mature, and there are already many types of MPPT controllers in circulation on the market. MPPT control is generally divided into traditional algorithms and some new algorithms proposed in recent years. Traditional MPPT control methods include P&O method (P&O), conductance increment method, etc.[2], and new algorithms include fuzzy control and neural network algorithms. These algorithms can achieve better MPP tracking results in a single photovoltaic cell system or multiple photovoltaic cells running in a uniform state. They also have their own advantages and disadvantages. It is necessary to select a suitable control method based on the actual situation[3]. But in fact, due to the influence of external factors such as houses, plants, dark clouds, and dust on the surface of

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photovoltaic cells, some components of the photovoltaic array will be blocked, resulting in uneven illumination and partial shadowing of photovoltaic cells. The shaded component becomes a load, which will cause a power drop, and may also cause a hot spot effect to cause permanent damage to the photovoltaic cell[4]. In order to prevent the hot spot effect, manufacturers will connect diodes in series or parallel at both ends of the photovoltaic cell, but in this way the operating state of the photovoltaic system will become complicated, and there will be a situation where the output power of the system is multi-peak. In this case, most MPPT controllers cannot track the maximum power point correctly. For example, the incremental conductance(INC) method uses the slope of the photovoltaic output power curve at the maximum power point to be 0 to track the MPP. In the case of multiple peaks of partial shadows, there will be multiple points with a slope of 0, and "misjudgment" will occur. According to statistics, among the photovoltaic cells currently installed and used, the power loss due to partial shadows is about 70%[5]. Therefore, the research on the working state of photovoltaic cells in partial shadows and their MPPT control is particularly important. This kind of maximum power point tracking problem for the multi-peak output power of photovoltaic cells is generally called global maximum power point tracking (GMPPT).

In recent years, many experts and scholars have conducted research on GMPPT control. In literature[6], parallel compensation is added to each photovoltaic cell. When the photovoltaic array is in partial shadow, the compensation circuit works, and the terminal voltage of the shaded component is maintained. This method can correct the output of the photovoltaic cell to a single peak value, avoiding the occurrence of multiple peaks, and then use the traditional MPPT control to make the photovoltaic system work at the maximum power point. However, this method has a large number of compensation circuits connected in parallel, which makes the entire system complicated and expensive. The applicable occasions are places where shadows exist for a long time, and the applicability is poor. Literature[7] uses structure parallel (SP) and mesh The output characteristics of the four photovoltaic array structures, including the total-cross-tied structure (TCT), the bridge structure (BL), and the honeycomb structure (HC), under the same area and different shapes and types of local shadows are compared, and the distribution structure of the photovoltaic cells is reduced. The influence of partial shading on the output power; Literature[8] proposed a photovoltaic array reconstruction method based on the total-cross-tied connection (TCT) structure based on the literature[7], which can adjust the free structure part of the photovoltaic according to different shading modes. The connection mode of the board determines the best connection relationship. Compared with the higher output power before reconstruction, the PU characteristic curve tends to be single-peak. This kind of improvement based on the distribution structure of photovoltaic panels requires adjustments to the hardware of photovoltaic panels, which are generally used in large-scale photovoltaic power generation sites, and are not suitable for small-scale photovoltaic power generation circuit lights, stop signs, etc. Therefore, this paper carries out mathematical modeling of the photovoltaic system, and analyzes the output of the photovoltaic system in the case of partial shadows, and then proposes an improved MPPT control method based on the P&O method. A Matlab/ Simulink simulation model is built, and the experimental results show that the proposed control method can enable the photovoltaic system to accurately track the maximum power point in the case of partial shadows.

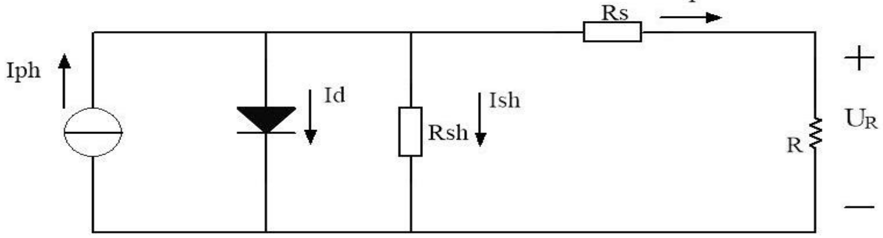

Figure 1. Single photovoltaic cell equivalent circuit

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2. Photovoltaic cell modeling and simulation

Photovoltaic cells generate electricity based on the photovoltaic effect. When the semiconductor PN junction is exposed to light, electron-hole pairs are generated inside. The electrons move to the N zone and the holes move to the P zone. Finally, a photogenerated electric field is formed. An electromotive force is generated between the zones[9]. The equivalent circuit of a typical single photovoltaic cell is shown in figure 1.

Short-circuit current and no-load voltage are two important parameters of solar cells[10]. Under standard light intensity (generally 1000W/m2), the current flowing through the battery when the output terminal is short-circuited is the short-circuit current; when the output terminal is open, the voltage across the battery is the no-load voltage.

Using Kirchhoff's law in the circuit shown in Figure 1-1, the following three formulas can be obtained:

$$\begin{cases} I_{ph} = I_{\mathrm{d}} + I_{sh} + I \\ I_{\mathrm{d}} = I_o\left(e^{\frac{qU_d}{AKT}} - 1\right) \\ U_{\mathrm{d}} = U + I \cdot R_s \end{cases} \tag{1}$$

In the formula, A, q, K, and T are all constants.

The constant in the above formula is difficult to know in actual use, so in order to simplify the model, the leakage current is often ignored[11]. Combining the three formulas and simplifying Iph, Io, and Rsh, the four-parameter model most commonly used in engineering can be obtained, as shown in formula (2):

$$I = I_{sc}\left[1 - C_1\left(e^{\frac{U}{C_2 U_{oc}}} - 1\right)\right] \tag{2}$$

In the formula, $C_1 = I_o/I_C$, $C_2 = \frac{1}{ln(1/C_1+1)}$

Suppose the voltage and current at the maximum power point are U_m, I_m respectively, then there are $C_1 = \left(1 - \frac{I_m}{I_{sc}}\right) \cdot e^{-\frac{U_m}{C_2 U_{oc}}}$, $C_2 = \left(\frac{U_m}{U_{oc}} - 1\right)\left[ln\left(1 - \frac{I_m}{I_{sc}}\right)\right]^{-1}$

In actual operation, photovoltaic modules will be affected by light intensity and battery temperature, so the four-parameter model should be compensated according to the following formula[12]:

$$\begin{cases} U_{mb} = U_{\mathrm{m}} \ln(e + b\Delta S)(1 - c\Delta T) \\ U_{ocb} = U_{oc} \ln(e + b\Delta S)(1 - c\Delta T) \\ I_{scb} = I_{sc}(S/S_{ref})(1 + a\Delta T) \\ I_{mb} = I_m(S/S_{ref})(1 + a\Delta T) \\ \Delta T = T - T_{ref} \\ \Delta S = S - S_{ref} \end{cases} \tag{3}$$

The photovoltaic module model used in this simulation is TSM-240PC/PA05, and the four parameters Isc, Uoc, Im, and Um given by the manufacturer are 8.37A, 37.2V, 7.89A, and 30.4V, respectively.

After substituting the above parameters, according to formula (2) and (3), modeling in Simulink is shown in Figure 2.

After packaging the model, the subsystem is shown in Figure 3. The input S is the light intensity (W/m^2), T is the temperature (℃), and U_{pv} is connected to the output of the battery, which is the feedback voltage.

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Using the controlled variable method, keep the temperature at 25℃ and change the light intensity ($800W/m^2$, $1000W/m^2$, $1200W/m^2$ respectively), and the P-U and I-U curves of the PV output obtained are shown in Figures 4 and 5 respectively.

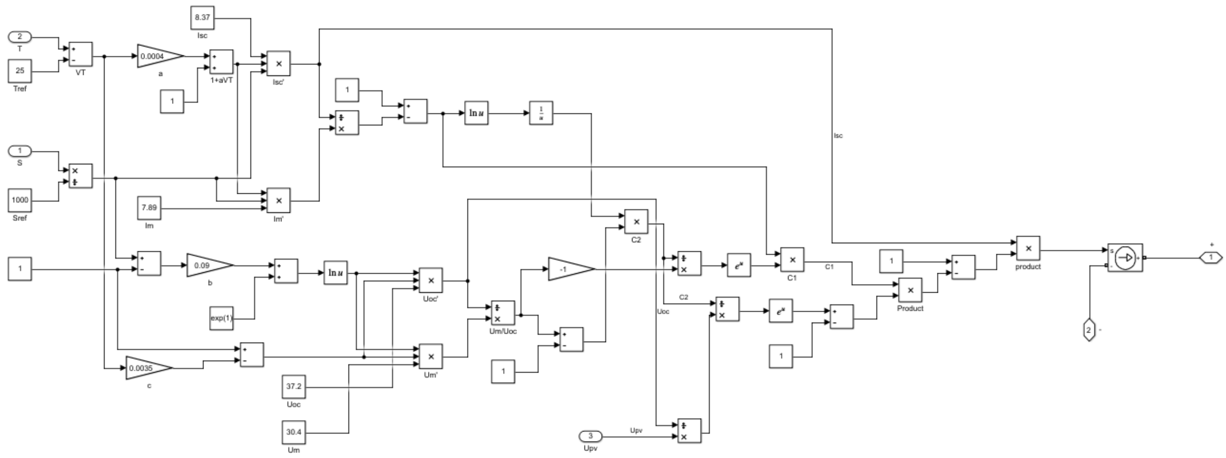

Figure 2. Photovoltaic cell simulation model

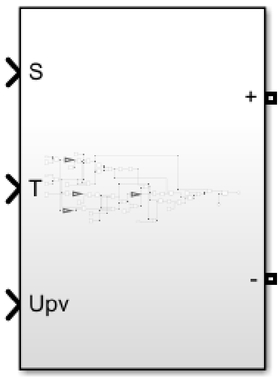

Figure 3. Photovoltaic cell package module

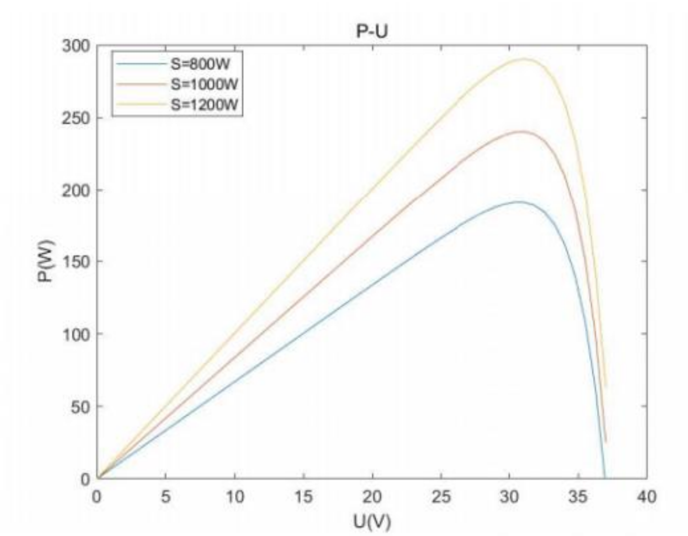

Figure 4. P-U curve

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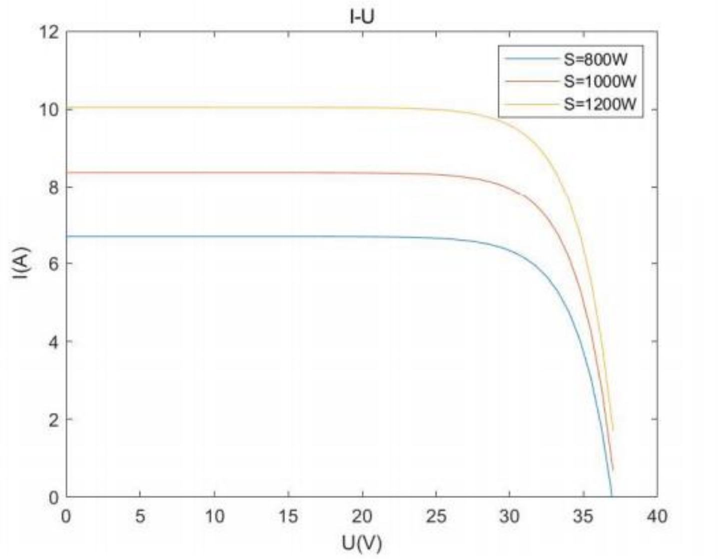

Figure 5. I-U curve

It can be seen that while keeping the ambient temperature constant, as the light intensity increases, the output power also increases.

3. Simulation analysis of photovoltaic cell working status under partial shadow

For the output power curve obtained above, it can be seen that it is a single peak value. MPPT control is relatively simple. In recent years, there are various algorithms that can better track the output to the maximum power point. The main algorithms are P&O method and fuzzy control. Method, particle swarm algorithm, etc. [13]. However, the output curve of the photovoltaic system in actual operation will be more complicated. Due to the limited output of a single photovoltaic cell, in order to increase the total output voltage or current of the photovoltaic system, manufacturers often connect multiple single photovoltaic cells in series or in parallel. Generally, such photovoltaic cells are combined into "substrings" and "substrings". "After connecting several "substrings" in parallel, a photovoltaic array is formed.

Figure 6 and 7 are schematic diagrams of two photovoltaic cells connected in series and in parallel respectively.

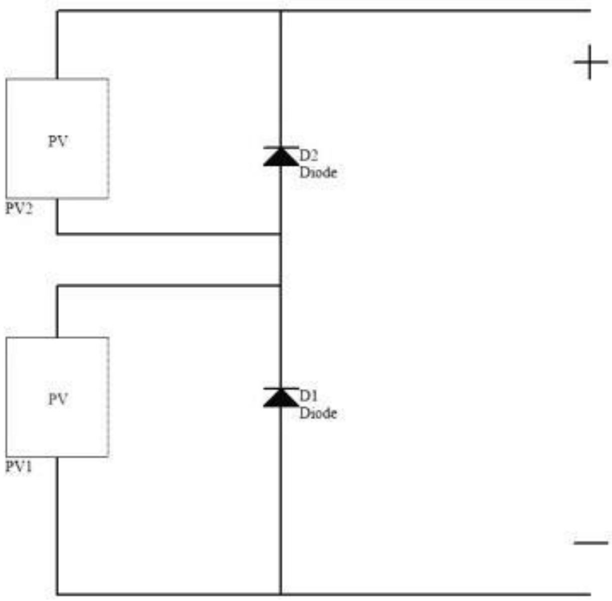

Figure 6. Series circuit of two photovoltaic cells

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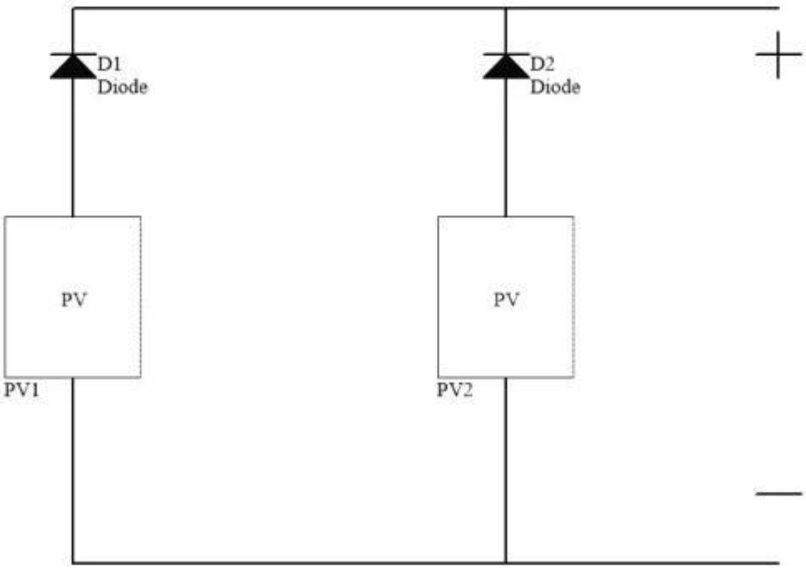

Figure 7. Parallel circuit of two photovoltaic cells

In figure 6 and 7, D1 and D2 are bypass diodes and blocking diodes respectively, which are all protection diodes set up to prevent the hot spot effect. When the two photovoltaic cells receive different light intensity, the total output voltage Uoc will be greater than the output voltage of a certain battery. If no protection diode is added, current will flow back into the photovoltaic cell, and the photovoltaic cell will become a load that consumes electricity from a power source. At this time, a hot spot effect will occur. After the protection diode is added, the current will flow through the diode, which plays a role in protecting the photovoltaic cell.

In order to obtain the specific output characteristics of the photovoltaic array under partial shadows, this paper simulates in MATLAB based on the above model. In order to simulate the shadow effect, this paper sets the light intensity of the two photovoltaic cells to $800W/m^2$ and $1000W/m^2$ respectively (it should be $1000W/m^2$ under normal operating conditions), and simulates the output of the photovoltaic array in series and parallel connections. The structure is shown in Figure 8 and 9.

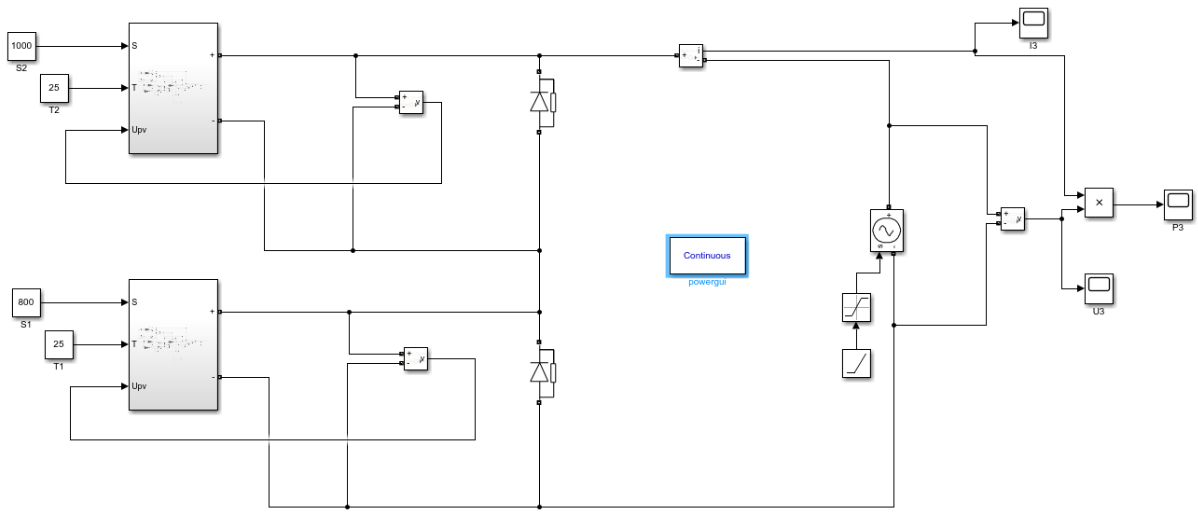

Figure 8. Photovoltaic substring simulation structure diagram

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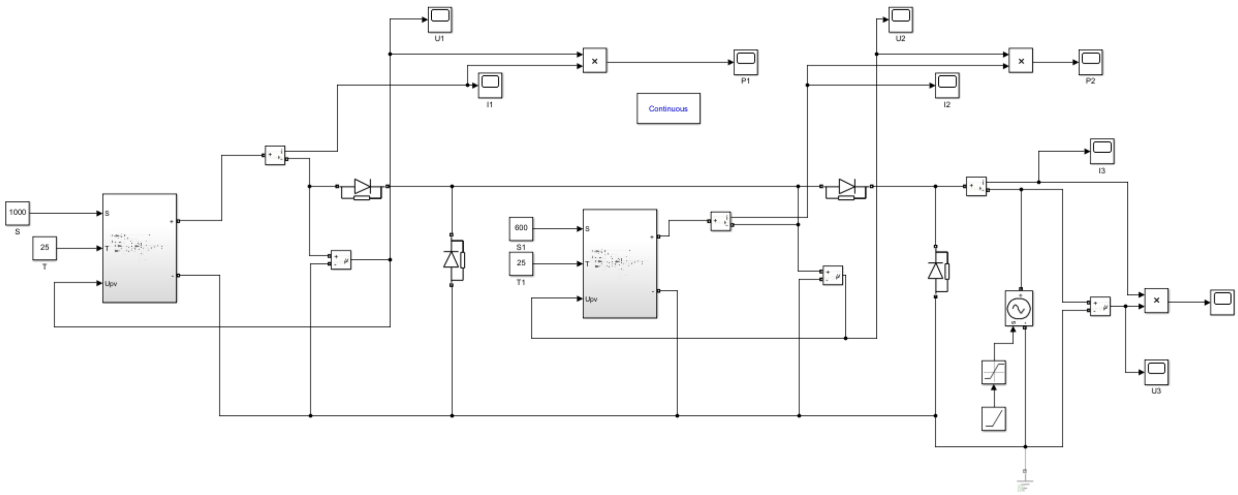

Figure 9. Photovoltaic sub-column simulation structure diagram

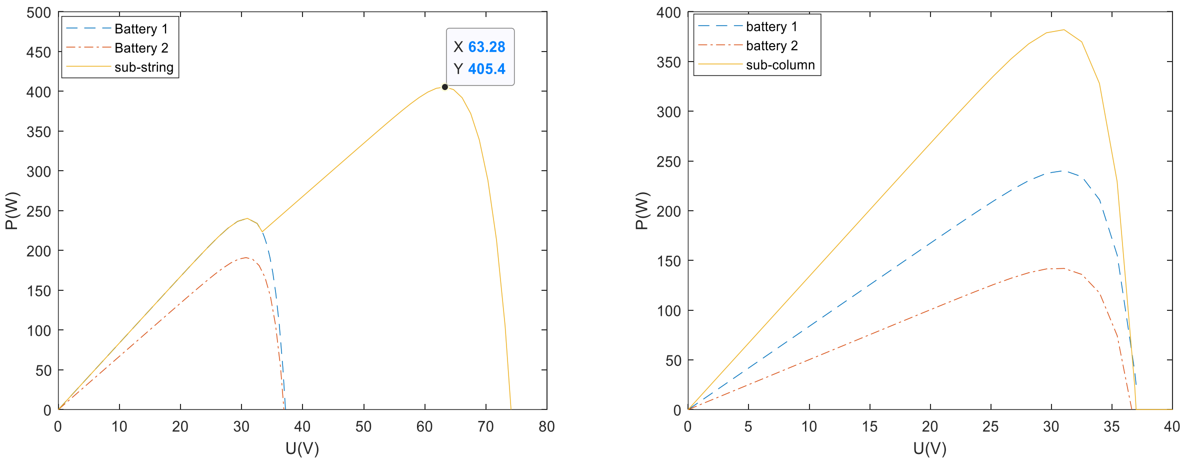

Figure 10. PV sub-string and sub-string output curve

The results are shown in Figure 10. In the case of sub-columns, when the sub-column output voltage is low, battery 1 and battery 2 are both working, and the sub-column output power is the sum of the two; when the sub-column voltage continues to increase, to a certain point, the sub-column voltage will exceed The voltage of the battery covered by the shadow, at this time, D2 bears the reverse voltage and cuts off, preventing the current from flowing back into the battery. At this time, the output power of the sub-column is the same as that of battery 1. It should be emphasized that the conduction voltage drop of all the bypass diodes is set to 0V during the simulation, otherwise the output power of the substring obtained will be slightly lower than the sum of the outputs of the two batteries, and it will not appear as a curve overlap. Therefore, the output power curve of the sub-string is single-peak, this characteristic can achieve better control effect by using the traditional MPPT control method, and the situation of the sub-string is more complicated. When the substring current is less than any battery current, the output characteristic is shown in the second half, that is, the output power is the sum of the two battery powers. When the substring current is greater than the current of the battery 2, the battery 2 is cut off by the bypass diode. The string power appears as the power of battery 1. In this case, the power curve of the sub-string is multi-peak, and each time the battery with different light intensity in series increases, the peak point will increase by one. In this case, directly using the MPPT control method will track the error to the maximum power point.

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4. Research on MPPT control method under partial shadow

This paper first uses the traditional perturbation observation method to simulate the photovoltaic substring. The set conditions are that the temperature is 25℃, and the light intensity of battery 1 and battery 2 are $800W/m^2$ and $1000W/m^2$, respectively. The power curve is shown in Figure 11. It can be seen that the tracked power point is about 230W. This value corresponds to the lower peak point in Figure 10, not the true maximum power point of the curve. The reason for this is that the principle of the P&O method is to compare the actual voltage value V with the expected value V_{ref}. When the value is less than V_{ref}, the disturbance is applied. If V changes in the direction of V_{ref}, continue to apply in the same direction. Disturbance, if V is far away from 6, the disturbance is applied in the opposite direction. However, because there are multiple power extreme points in the photovoltaic sub-string, the P&O method will start the reverse disturbance after V exceeds the first extreme point, and the result of the final disturbance will remain at the previous power point. Therefore, we need to improve the traditional MPPT control method to track the Global Maximum Power Point (GMPP).

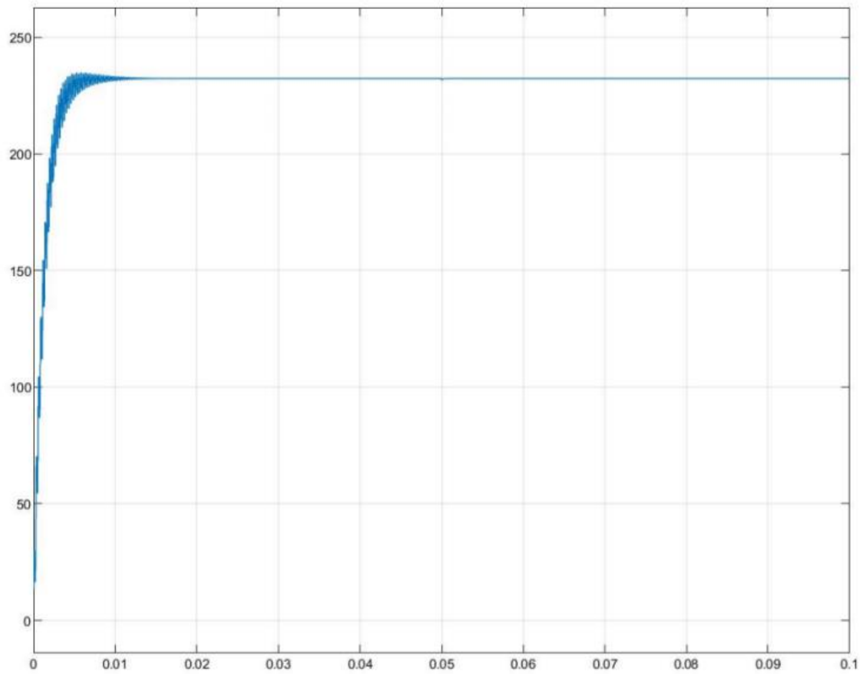

Figure 11. P&O method MPPT curve

According to the analysis of literature[14] , when the illumination of battery 1 remains unchanged and battery 2 is shaded by shadows, the maximum power value of the photovoltaic substring under uniform illumination is in the middle of its two power points under partial shadow; The extremum of the front wave peak under the non-uniform shadow remains unchanged and coincides with the power curve of battery 1, and the power is equal to one-half of the maximum power of the sub-string under uniform illumination. This can lead to a conclusion: $1/2P_{MPPT} \leq P_{GMPP} \leq P_{MPPT}$ (The global maximum power of the substring under local shadows is greater than one-half of the power under uniform illumination, but it is less than the maximum power point under uniform illumination). Combining this conclusion with the principle of the perturbation observation method analyzed in the previous article, this paper has obtained a simple global maximum power point tracking method (GMPPT) method: first use the perturbation observation method to track the maximum power point, and then combine it with the sub The string is compared with P_{MPPT} under uniform illumination. If it is less than P_{MPPT}, the disturbance will continue to be applied, and then the correct GMPP can be tracked. According to this principle, this article made a photovoltaic MPPT system model as shown in Figure 12.

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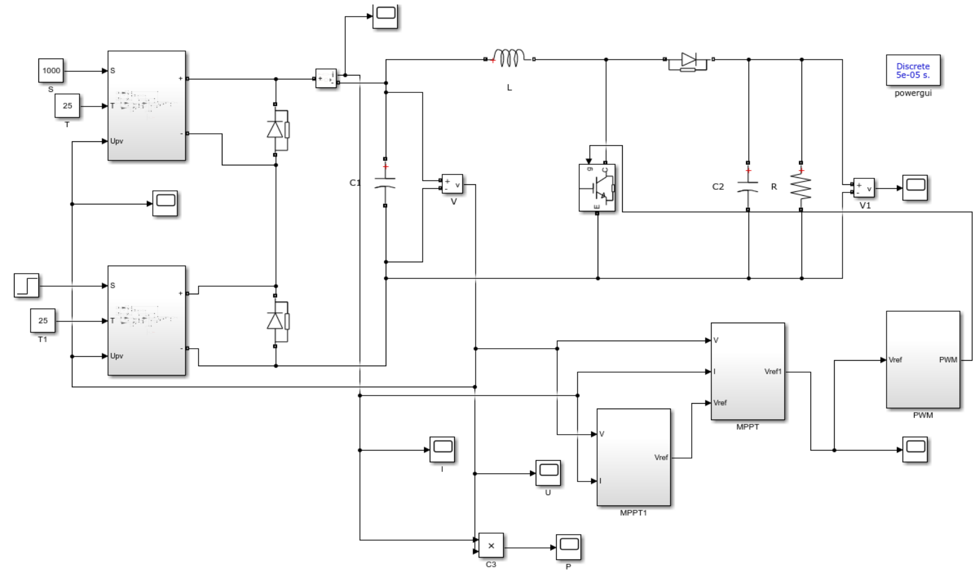

Figure 12. Improved P&O method MPPT model

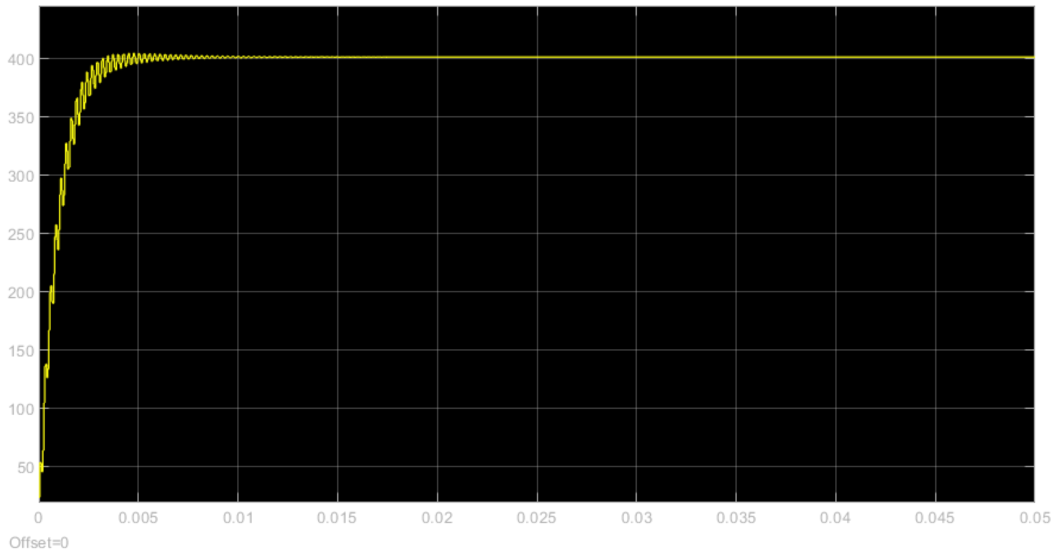

Figure 13. Case 1

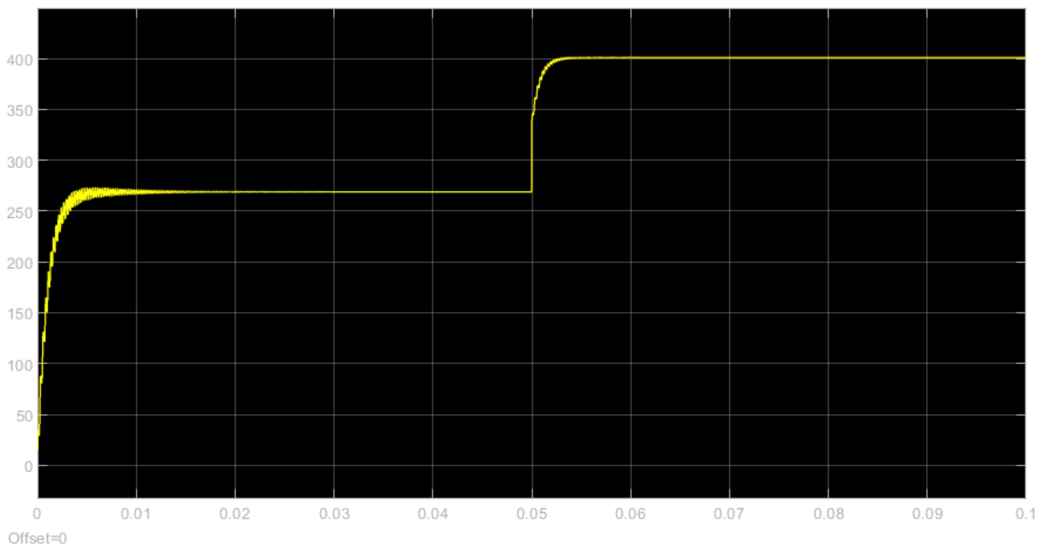

Figure 14. Case 2

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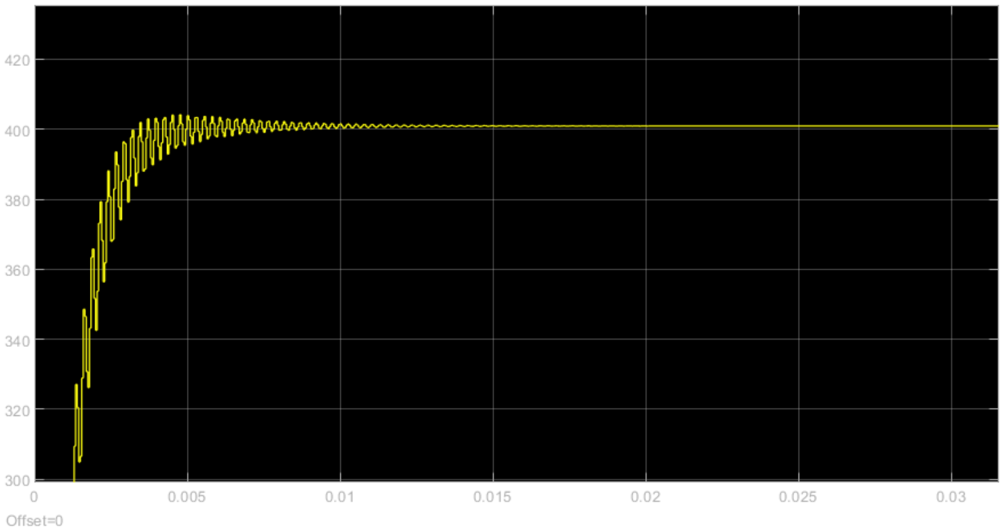

Figure 15. Enlargement of case 1

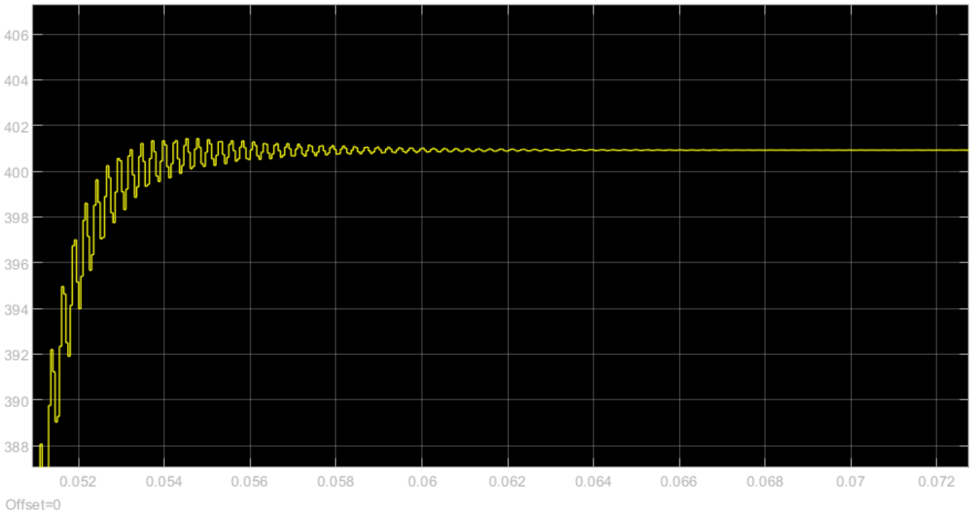

Figure 16. Enlargement of case 2

This paper simulates the situation of two kinds of partial shadows. The first situation is that the shadow exists for a long time, such as being blocked by buildings, and there are obstructions such as leaves and bird droppings on the photovoltaic panel. The light intensity of battery 1 is $1000W/m^2$, the light intensity of battery 2 is $800W/m^2$, and the simulation time is set to 0.05 Second; the second situation is that the shadow exists for a short time. For example, when it is covered by dark clouds, the light intensity of battery 1 is $800W/m^2$, and the light intensity of battery 2 is shaded at first, and the light intensity is $800W/m^2$, and then the light intensity returns to $1000W/m^2$ after the shadow disappears. The step module is used in the model to simulate sudden changes in light intensity, and the value steps from 800 to 1000 at 0.05 seconds. The total simulation time is 0.1 seconds. The simulation results are shown in Figures 13 and 14. As shown in the output curve of the substring in Figure 10, the theoretical global maximum power point of the substring should be 402.7W. In order to get accurate results, zoom in to Figures 13 and 14 to obtain Figures 15 and 16. As shown in the figure, in case 1, 400W was tracked at 0.01 second, but it did not stabilize immediately. Instead, it oscillated back and forth at 400W until 0.02 second. In case 2, the light intensity changed from $800W/m^2$ to $1000W/m^2$ at 0.05 second. The power tracked to 401W at 0.06 seconds, and the oscillation continued for about 0.01 seconds thereafter.According to the data obtained in Figures 10, 15, and 16, it can be seen that the accuracy of this control method is more than 99%, the error is small,

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and there is no obvious overshoot, and it can successfully track the global maximum power. point. However, in the process of tracking, due to the characteristics of the P&O method, the power curve has relatively obvious oscillations, which makes the tracking time prolonged, and there is still a period of oscillation before stabilization. This will also increase the power loss and needs to be improved.

5. Conclusion

Based on the results of simulation experiments and data analysis, this paper proves that the improved P&O method proposed can achieve the purpose of tracking GMPP. However, as can be seen from Figures 15 and 16, the P&O method will oscillate more violently during the process of tracking to the maximum power point, which will prolong the tracking time, and there will be a long period of oscillation after reaching the maximum power point. This is also the shortcoming of this control method. In the future, it is necessary to optimize and improve the control method to increase the accuracy of the algorithm while taking into account the tracking speed.

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